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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The first phase of the research involved a study of positive and negative ions in carbon dioxide gas. The identities of the ions produced in CO_2 by electron bombardment were ascertained, and the conversion of these ions to other types by ion-molecule reactions was studied. The mobilities of various species were measured. In the second phase, ~~we measured~~ the mobilities and longitudinal diffusion coefficients of positive alkali and negative halogen ions in the noble gases. Interaction potentials were determined from the mobility data.

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IONIC TRANSPORT AND COLLISION PROCESSES IN LASER GASES

FINAL REPORT

by

E.W. McDaniel

July 1, 1978

U. S. ARMY RESEARCH OFFICE

ARO Project Number: P-12134-P
Grant Numbers: DAHC04-74-G-0192
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THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION, UNLESS SO DESIGNATED BY OTHER AUTHORIZED DOCUMENTS.

A. RESEARCH PERFORMED WITH A.R.O. SUPPORT

I. Studies of Ions in CO_2 Gas. The first phase of our A.R.O. research involved a study of positive and negative ions in carbon dioxide gas. The principal objective was to obtain data that would be useful in the modeling of CO_2 lasers. Our findings are summarized below:

We have investigated in drift tube mass spectrometers the identity and the transport properties of ions formed in CO_2 gas at pressures ranging from 10^{-4} torr to 762 torr. Under bombardment by low energy (20-100 eV) electrons in the ion source, the primary positive ion is predominantly CO_2^+, with traces of C^+, O^+, and CO^+. The predominant ion becomes O_2^+ at pressures above 100 microns (0.1 torr), and clustering of CO_2 molecules to the O_2^+ occurs even at pressures below 1 torr. Breakup of the clusters also occurs, the ion identity changing many times in the drift region. The zero-field reduced mobility of the $O_2^+\cdot(CO_2)_n$ charge carrier is a function of pressure, and varies from (1.30 $\pm$ 0.03) cm^2/V-sec at 0.2 torr to (1.18 $\pm$ 0.03) cm^2/V-sec at 1 torr.

The sole negative ion produced directly by the electron bombardment is O^-, which clusters to form the stable ion CO_3^-, whose reduced mobility is (1.27 $\pm$0.06) cm^2/V-sec for $E/N \leq 60$ Td at all pressures below 1 torr. At much higher pressures and under somewhat different conditions (above 30 torr and using beta source ionization), ions in CO_2 are observed to form multiple clusters, the population distribution among the clusters being strongly dependent on gas temperature. The zero-field reduced mobility of the charge carrier is largely independent of the identity of the core ion, and varies with pressure from roughly 1.2 cm^2/V-sec at 35 torr to about 1.0 cm^2/V-sec at 762 torr. We have measured the rate coefficient for the reaction $O^- + 2CO_2 \rightarrow CO_3^- + CO_2$ at room temperature and obtained the result $(7-14) \times 10^{-28}$ cm^6/sec at E/N = (80-100) Td.

A full account of this work appears in Ref. 2 of Section C of this report.

II. Measurements on Alkali and Halogen Ions in the Noble Gases. We have made extensive measurements of the mobilities and longitudinal diffusion coefficients of alkali and halogen ions in the noble gases over a wide range of E/N. This work is discussed in Refs. 5, 7, 8, 9, 11, 12, 15, and 16.

The measured transport coefficients are of direct interest in their own right in the modeling of electrical discharges and other phenomena involving plasmas and ionized gases. However, our strongest motivation for measuring the mobility of ions in gases over a wide range of E/N has been to obtain data from which information on ion-neutral interaction potentials can be derived for a wide range of separation distance. The interaction potential for a two-particle system is one of the most fundamental properties of the system. It determines the mutual scattering behavior of the particles and hence the transport properties. The interaction potential also determines many properties of the system that is formed if the two particles can temporarily or permanently combine. In the case of radiative processes, for example, the interaction potentials for the upper and ground states of a neutral diatomic molecule or ion determine the wave functions, transition probabilities, and spectral features. The standard beam scattering technique used to obtain information about the interaction potential for an ion-neutral system covers a much smaller range of separation distance than does the new method mentioned here. Our work on obtaining interaction potentials for combinations of noble gas atoms with the positive alkali ions and the negative halogen ions has gone forward without difficulty. We are also planning to use these potentials to obtain the interaction potentials for various combinations of neutral noble gas atoms. This plan is discussed in our research proposal submitted to A.R.O. on Jan. 12, 1977. These data should be of considerable interest in connection with noble gas-noble gas excimer gas lasers.

In addition, we are using our diffusion data to test the new unpublished theory of ionic diffusion in gases at arbitrary electric field strength that has been recently developed by E.A. Mason and L.A. Viehland.

B. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD

Earl W. McDaniel, Regents' Professor of Physics (Project Director).

Ian R. Gatland, Professor of Physics

Harry W. Ellis, Post-doctoral Fellow

Walter F. Morrison, Graduate Research Assistant-Ph.D. Physics 1977

Robert Y. Pai, Post-doctoral Fellow

David R. James, Graduate Research Assistant-Ph.D. Physics 1975

Garth R. Akridge, Graduate Research Assistant-Ph.D. Physics 1975

Fred L. Eisele, Post-doctoral Fellow

Wayne M. Pope, Post-doctoral Fellow

Michael G. Thackston, Graduate Research Assistant (will receive Ph.D. in Physics in 1978).

C. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

1. "Transport Properties of Positive and Negative Ions in CO_2," by R.Y. Pai, H.W. Ellis, I.R. Gatland, and E.W. McDaniel, Gaseous Electronics Conf. Rolla, Mo., Oct. 22-24 (1975).
2. "Ion identity and transport properties in CO_2 over a wide pressure range," by H.W. Ellis, R.Y. Pai, I.R. Gatland, E.W. McDaniel, R. Wernlund, and M.J. Cohen; Jour. Chem. Phys. 64, 3935 (1976).
3. "Studies of Ion Plasma Chemistry with Drift Tube Mass Spectrometers" by E.W. McDaniel, Third Int. Symposium on Plasma Chemistry, Limoges, France 1977.
4. "Cs^+-Kr and Cs^+-Xe Interaction Potentials" by I.R. Gatland and E.W. McDaniel, Int. Conf. on the Physics of Electronic and Atomic Collisions, Paris, July 1977.
5. "Tests of Alkali Ion-Inert Gas Interaction Potentials by Gaseous Ion Mobility Experiments" by I.R. Gatland, L.A. Viehland, and E.A. Mason, J. Chem. Phys. 66, 537 (1977).
6. "Transport Properties of Gaseous Ions Over a Wide Energy Range," by H.W. Ellis, R.Y. Pai, E.W. McDaniel, E.A. Mason, and L.A. Viehland, Atomic Data and Nuclear Data Tables 17, 177-210 (1976).
7. "The Li^+-He Interaction Potential," by I.R. Gatland, W.F. Morrison, H.W. Ellis, M.G. Thackston, E.W. McDaniel, M.H. Alexander, L.A. Viehland, and E.A. Mason, J. Chem. Phys. 66, 5121 (1977).
8. "Further Tests of the Generalized Einstein Relation: Cs^+ Ions in Ar, Kr, and Xe" by M.G. Thackston, F.L. Eisele, W.M. Pope, H.W. Ellis, and E.W. McDaniel, Jour. Chem. Phys. 68, 3950 (1978).
9. "Mobilities and Interaction Potentials for Cs^+-Ar, Cs^+-Kr and Cs^+-Xe," by I.R. Gatland, M.G. Thackston, W.M. Pope, F.L. Eisele, H.W. Ellis, and E.W. McDaniel, Jour. Chem. Phys. 68, 2775 (1978).
10. "Gaseous Ion Transport and Reaction Studies Using Drift Tube Mass Spectrometers" by H.W. Ellis and E.W. McDaniel, Invited Paper presented at the U.S.-Japan Joint Seminar on the Glow Discharge and Its Funamental Processes, Boulder, Colorado, July 12-15, 1977.
11. "Mobilities and Interaction Potentials for Cl^--Ne, Ar, Kr, Xe," to be submitted to J. Chem. Phys.

12. "Longtiudinal Diffusion Coefficients for Cl^- Ions in Ne, Ar, Kr, and Xe," to be submitted to J. Chem. Phys.

13. "Transport Properties of Gaseous Ions Over a Wide Energy Range-Part II," by E.W. McDaniel, H.W. Ellis, D.L. Albritton, E.A. Mason, and C. Lin, to be submitted to Atomic Data and Nuclear Data Tables, August, 1978.

14. "Studies of Ion Transport and Reactions in Gases with Drift Tube Mass Spectrometers," by E.W. McDaniel and I.R. Gatland, submitted to 4th Europhysics Conf. on Atomic and Molecular Physics of Ionized Gases, Essen, Germany, Sept. 18-20, 1978.

15. "Mobilities and Interaction Potentials for Rb^+-Ar, Rb^+-Kr, and Rb^+-Xe," by I.R. Gatland, D.R. Lamm, M.G. Thackston, W.M. Pope, F.L. Eisele, H.W. Ellis, and E.W. McDaniel, to be submitted to J. Chem. Phys.

16. "Longitudinal Diffusion Coefficients for Rb^+-Kr, Rb^+-Xe, K^+-Kr, and K^+-Xe," by W.M. Pope, F.L. Eisele, M.G. Thackston, H.W. Ellis, and E.W. McDaniel, to be submitted to J. Chem. Phys.

17. "Bibliography: Sources of Information on Phenomena of Interest in Gas Laser Research and Development," by E.W. McDaniel, H.W. Ellis, F.L. Eisele, and M.G. Thackston, Redstone Arsenal, Ala.,U.S.Army MICOM Report, RH-77-1, 202 pages. January, 1977.

18. "Compilation of Data Relevant to Rare Gas-Rare Gas and Rare Gas-Monohalide Excimer Lasers," by E.W. McDaniel, M.R. Flannery, H.W. Ellis, F.L. Eisele, W. Pope, and T.G. Roberts, Redstone Arsenal, Ala, U.S. Army MICOM Report H-78-1, 892 pages. December, 1977.

Ref. 17 above is a listing of 2300 data compilations, review articles, bibliographies, and books that we believe to be of interest to persons engaged in research and development on gas lasers. The work was financed entirely by MICOM, but is mentioned here because of the relevance to our ARO grant.

Ref.18 above is another report which was financed entirely by MICOM. It contains 892 pages of graphical and tabular data on structural and collisional properties of atomic and molecular species that are of interest in research and development of excimer gas lasers.